The following gives an overview of the results of a continued study on the feasibility of the large wide field corrector elements as requested by the WFMOS Feasibility Study Review Committee. The objectives were to determine whether or not the glass blanks can actually be purchased with sufficient homogeneity characteristics and to re-analyse the tolerances for the corrector. To achieve this, we have sent emails to most of the groups that have or are building comparably sized optics and have received responses from some of them. We also sent queries to the glass fabrication houses (Schott, Ohara, and Corning) for information on the availability of these glass blanks. Prime Optics was contracted to look at the tolerancing issues and to help explore homogeneity issues.

**Executive summary**

We failed to get feedback from all sources, however the bulk of the feedback is positive. We did not approach any of the lens fabricators as we feel the issues are in the glass fabrication stage. The indicators are that the glass for the WFMOS corrector can be acquired. It may be that Fused Silica (FS) is preferred over a BK7-type glass as Corning appears to be able to produce the FS. We do not have sufficient information on the BK7-type glasses to make any firm conclusions on that type of glass.

The tolerancing evaluation employed a conservative analysis in which the tolerances, though tight in many cases, are not beyond reason. In order to minimize the tolerancing risk, it will be important that the fabrication steps for the corrector and its mount be carefully considered.

**1.1 Objectives**

1. The WFMOS feasibility study review committee has judged that the largest remaining technical risk to WFMOS is the availability of glass of sufficient volume and with the required homogeneity for the critical first corrector lens and the ADC. Successful delivery of similar sized optics to existing projects was not demonstrated at the review, yet problems in these areas have been experienced by projects requiring smaller glass elements (e.g. CFHT Megacam corrector). Clarification of these issues is to be sought by working directly with the two identified glass houses (Ohara and Schott) and by presenting examples of successfully realized lenses of comparable size together with a discussion of the problems encountered during their development lifetimes (e.g. 2df, VISTA, LSST, etc.).

2. The committee recommended further assessment of the optical and mechanical tolerances of the wide field corrector by considering the effect of errors on image quality in annular regions, not just on global rms values.

**1.2 The Potential Problem**

The following image shows the potential issue that can be encountered when producing the glass for the front element of the corrector assembly. When large volumes of glass are requested for elements with large surface curvatures, it is often the case that the glass boule is slumped to reduce the amount of glass that is ground away in the generation of the surfaces. This process can introduce index inhomogeneity and birefringence that deteriorate the imaging performance of the optic. Figure 1 shows an element from the CFHT Megacam corrector in which the birefringence variations are significant and most likely attributed to the slumping process.

The question is whether or not this is a significant risk to the WFMOS corrector.
1: Birefringence measurement of a slumped BK7 equivalent lens.

1.3 Similar Systems to WFMOS

The following instruments/facilities have or are in the process of producing transmissive element similar in nature to those required for the WFMOS wide field corrector and ADC:

- VISTA telescope
- 950 mm diameter corrector fabricated by Corning
  - Contact Will Sutherland (wjs@roe.ac.uk), Alistair McPherson (project manager, amm@roe.ac.uk)
- LSST telescope
  - Corrector under design at Lawrence Livermore National Labs
  - Contact Scott Olivier (LLNL), Steve Kahn (in charge of camera, skahn@slac.stanford.edu), Chuck Claver (telescope scientist, cclaver@noao.edu) and Donald Sweeney (project manager, sweeney@lsst.org)
- DES corrector for the Blanco telescope
  - ~1.1 meter Corrector under design by University College London and University of Chicago
  - Contact DES-optics@fnal.gov (DES optics mailing list)
- Corrector for the Discovery Channel Telescope
  - 1.1 meter corrector under development for the Lowell Discovery Channel Telescope. The form of this corrector is very similar to that for WFMOS
  - Contact E. W. Dunham at Lowell Observatory or M. J. MacFarlane at Goodrich Corporation
- 2dF corrector for the AAT
  - 880 mm Corrector for the 2dF fiber positioner on the AAT
  - Contact Peter Gray, Keith Taylor
- Holographic collimators at LLNL
  - Matched pair of 1-meter sized transmissive lenses for holographic exposure system
  - Contact Mike Rushford (rushford1@llnl.gov), Jerry Britten (britten1@llnl.gov), or Sham Dixit (dixit1@llnl.gov)
- CFHT Megacam corrector
1.4 Optical Tolerance Analysis

A detailed optical tolerancing analysis was undertaken under a subcontract to Prime Optics, under the terms of a contract amendment to the Feasibility Study. The report from Prime Optics forms an attachment to this document.

The tolerancing study was based on the feasibility study’s proposed 1.2-m aperture corrector, configured for the more challenging imaging requirements of HyperSuprime Cam. More than 50 manufacturing error sources were identified, and these were individually perturbed from their optimised values to quantify their effects on image quality. The analysis used a figure of merit based on the RMS image size, after demonstrating near-independence on image field location, and near-equivalence to an encircled energy criterion.

This analysis quickly identifies major contributors to image degradation. In particular, it will be important to locate the front two corrector elements (the largest elements) with great care. The front element should err towards being too thick rather than too thin. System optical performance is also sensitive to decentre of the first compound ADC component, so design of the ADC mechanism and housing will also require careful attention.

Combination of individual errors to derive an overall tolerance budget was made using the ‘RSS rule’ (adding image degradation factors in quadrature), which is expected to be highly conservative. A summary of preliminary suggested manufacturing tolerances is provided in the report, however the AAO extracted individual contributors from the tables in the report, and tightened some of the specifications somewhat to achieve an RSS combined image degradation near 10% (Table 1, below).

Table 1: AAO-amended corrector fabrication tolerances, based on Prime Optics’ report. The combined effect of errors of this magnitude would conservatively yield an image degradation near 10%.

<table>
<thead>
<tr>
<th>Component</th>
<th>RoC %</th>
<th>Conic %</th>
<th>Figure P-V λ, 633 nm</th>
<th>Thickness mm</th>
<th>Wedge TIR, mm</th>
<th>Mount Tilt, TIR, mm</th>
<th>Mount Decenter, mm</th>
<th>Decenter mm</th>
<th>Tilt, arcsec</th>
<th>Decenter, mm</th>
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<tbody>
<tr>
<td>1</td>
<td>0.05/0.1</td>
<td>0.2</td>
<td>1/4/4</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1/0.1</td>
<td>0.4</td>
<td>1/4/4</td>
<td>0.5</td>
<td>0.1</td>
<td>0.05</td>
<td>Comp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td>NA/0.8/0.1</td>
<td>1/4/4</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
<td>0.05</td>
<td></td>
<td>15</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>3B</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>4A</td>
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<td>1/1/1</td>
<td>2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.4</td>
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</tr>
<tr>
<td>4B</td>
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<td>0.5</td>
<td>1/1</td>
<td>0.5</td>
<td>0.2</td>
<td>0.1</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.8/0.2</td>
<td>-</td>
<td>1/1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
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</tr>
<tr>
<td>6</td>
<td>0.8/0.2</td>
<td>-</td>
<td>1/1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Particular care will be required in some areas, but the tolerances specified in Table 1 are regarded as quite achievable. It is expected that a tolerance analysis for similar corrector designs would yield broadly similar results with similar sensitivities – indeed a comparison with the analysis undertaken in the Purple Book for that earlier design shows just this.

The report from Prime Optics also points out the relative insensitivity of field angle of the image quality due to the major error sources. This is primarily due to the fact that the tightest tolerances reside in the front elements, which are closer to the pupil.
1.5 Conclusions

Based upon the information that we have been able to receive, the indicators are that the glass for the WFMOS corrector can be acquired. It may be that Fused Silica (FS) is preferred over a BK7-type glass as Corning appears to be able to produce the FS, though we have yet to find information regarding acquisition of a BK7 equivalent in comparable size.

The tolerancing evaluation employed a conservative analysis in which the tolerances, though tight in many cases, are not beyond reason. In order to minimize the tolerancing risk, it will be important that the fabrication steps for the corrector and its mount be carefully considered.

Further analysis and exploration should be carried out in the concept design phase to achieve the following:

1) Get further information from vendors on actual delivered performance for optics of this size (BK7-equivalent components in particular).

2) Perform a proper Monte Carlo tolerance analysis based upon a proper fabrication and assembly procedure, following further refinement of the optical design based on a selection of material for the largest elements.

3) Evaluate structural support performance for the WFC through Finite Element Analysis.

It will likely be required that the front elements of the corrector be acquired very early in the design/build phase of WFMOS since their performance will drive the rest of the corrector design. It may be desirable to cast the blanks during either the concept or preliminary design.

1.6 List of attachments

Appendix 1: Optical Tolerancing report from Prime Optics